Measurements of Turbulence in the Upper Layer with AUTOSUB

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LONG-TERM GOALS

The long term goal is to understand the dynamics of the upper layer of the ocean, specifically the roles of turbulence, Langmuir circulation and large scale vortices.

OBJECTIVES

1) To measure the turbulence, velocity and temperature fields in the upper layer in order to delineate the processes responsible for the heat and momentum fluxes

2) To develop the technical capability to operate from a wide variety of AUV and manned submersible vehicles

APPROACH

Heat, momentum and gas transfer between the ocean and the atmosphere involve wave breaking, turbulence and bubble generation, mixing by Langmuir circulation and shear induced eddies; all these processes are poorly understood (Thorpe et. al., 2002). These processes control the dynamics of much of the forcing of the upper layer of the ocean.

Measurements from the USS Dolphin showed enhanced turbulent dissipation above 'Law of the Wall' scaling with acoustically detected bubble clouds in the upper 4m of the water column during 5-9 m/s winds off San Diego (Osborn et. al., 1992). More detailed measurements by Agrawal et. al. (1992) show the enhanced dissipation extends to a depth $z \approx 10^5 u_*^2 / g$ where u_* is the friction velocity for the water and *g* the acceleration of gravity. Terray et. al. (1996) suggest that the significant wave height, H_s and the wave age, c / u_*, are relevant scaling parameters (c is the phase speed of the peak of the wave frequency spectrum). Another parameter they use is c', where the rate of energy input from the wind, *F*, is $F = c'\tau$. However, work by Annis and Moum (1995) and Gemmrich and Farmer (1999a & b) suggest that the parameters H_s, c', u_*, and z are not sufficient to scale the turbulence.

The surface turbulence affects the near surface bubble distribution and the transfer of gases and heat. Below this layer, Langmuir circulation (with vortices roughly aligned with the wind direction) contributes to the transport and distribution. Another large scale process is the shear induced eddies identified by Thorpe and Hall (1980) in Loch Ness. These vortices arise from a shear instability of the mean flow in the upper layer and thus their vorticity is aligned with the vorticity of the mean shear. In

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Loch Ness, the mean shear was in the direction of the wind and the vortices aligned perpendicularly to the wind. There they generated temperature ramps that produced more significant thermal features than those from the Langmuir circulation. The temperature signal from the ramps was observed by moving parallel to the wind direction and the temperature signal from the Langmuir circulation was observed by moving perpendicularly to the wind.

My approach is to perform turbulence measurements with airfoil probes for velocity fluctuations in conjunction with high resolution temperature and temperature gradient data from fast thermistors. These data are combined with data from other investigators in order to determine the interaction of the turbulence with breaking waves, bubbles, Langmuir circulation, and large scale eddies. We have used AUTOSUB in the past and are arranging access to that vehicle again in 2005. For the past 2 years we have used the submersible Forel in Lake Geneva.

WORK COMPLETED

Professors Steve Thorpe, David Farmer and I collected a unique data set with AUTOSUB in April 2000 in the upper layer of the ocean. The system included: Thorpe's forward and sideways looking sonar (Thorpe and Hall, 1983) to document bubble clouds, Langmuir circulation, and breaking waves; Farmer's resonator system (Farmer et. al., 1998) to determine bubble size distribution; and my turbulence package to measure the turbulent dissipation and wave statistics. This year has seen the publication of the second paper (Thorpe et. al., 2003) on the relation between the turbulence, Langmuir circulation, bubbles and breaking waves from measurements in a Scottish loch This paper tests (to the ability of the data) eight of the basic assumptions supporting models for bubble distributions and air-sea gas exchange. The assumption seem generally valid below $1.5H_s$ in winds around 11.5 m/s. The paper concludes by drawing "attention to several aspects of upper ocean dynamics for which data are not yet sufficient to construct realistic and quantitative models of transfer processes involving Langmuir circulation."

In November 2001 and again in October 2002, Dr Ulrich Lemmin (Laboratoire de Recherches Hydrauliques of the Ecole Polytechnique Fédérale de Lausanne), Steve Thorpe and I used the submarine FOREL in Lake Geneva to attempt to collect data in the mixed layer during a strong wind regime. Past measurements in Lake Geneva by Dr. Lemmin and Prof. Thorpe have focused on breaking progressive internal waves during stratification and the plume formation and boundary mixing during convective winter cooling.

RESULTS

The turbulence package we used on the FOREL is the same system used in the AUTOSUB measurements. It has nine channels of data: two shear probes (one measuring the cross stream horizontal velocity fluctuations and the other the vertical velocity component), temperature, temperature derivative, three accelerometers (for pitch, roll and heave), pressure and pressure derivative. The shear data are used to calculate the rate of dissipation of kinetic energy in 1 m horizontal bins. The temperature and temperature derivative data are combined and digitally filtered (Osborn et. al., 1992, using the method of Mudge and Lueck, 1994) to produce high resolution temperature traces with resolution of millidegrees. The pressure data from the turbulence package can be processed to produce a high resolution time series to estimate wave spectra (Osborn et. al., 1992). This allows us to estimate the significant wave height and period of the dominant waves. One data

channel is used to record signal pulses that are recorded concurrently on the thermistor array data in order to lock the two times series together unambiguously in time.

The data from both field test have been through preliminary processing to calculate time series of dissipation, temperature and temperature gradient variance. Preliminary integration of the thermistors array with the turbulence data has been accomplished and final integration of the data sets is planned for November 2003.

Figure 1. The submarine Forel with sensors in the deployed position before a dive on Lake Geneva in October 2002. The turbulence package is mounted in foam rubber in the brown tube along the port side of the submarine. The thermistor array is shown in the deployed position with thermistors and Nortek 3-D acoustic current meters. For launch, transit and recovery, the turbulence package is retracted about 2 meters and the thermistor array is folded onto the upper deck. For October 2002 the thermistors array was modified (as shown) to include horizontal as well as the previous (November 2001) vertical spacing of the sensors. This array appears to be the largest practical for use on the submarine.

IMPACT/APPLICATIONS

The development of the capability to sample turbulence in the surface and near surface regimes of the upper ocean in difficult weather conditions is vital to understanding the important and complex processes that occur there.

TRANSITIONS

The technology for turbulence measurements and interpretation that has been developed by the PI through ONR funding during the last 25 years is now well established in the oceanography community.

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